REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Washington Headquarters Service, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington, DC 20503.
PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT DATE	3. DATES COVERED *(From - To)*
28-07-1999	Annual Report	01-07-1998 to 30-06-1999

4. TITLE AND SUBTITLE

Behavior Self-Organization In Multi-Agent Learning

5a. CONTRACT NUMBER

5b. GRANT NUMBER
N00014-98-1-0779

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Bay, John S.
Vanlandingham, Hugh F.

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24060

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research
Program Officer Teresa McMullen ONR 342PS
Ballston Centre Tower One
800 North Quincy Street
Arlington, Virginia 22217-5660

10. SPONSOR/MONITOR'S ACRONYM(S)
ONR

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT

Approved for Public Release

19990802 028

13. SUPPLEMENTARY NOTES

14. ABSTRACT

There are four primary results of the first year of the project:

- It was discovered that clustering algorithms for pre-sorting high-dimensional datasets was not effective in improving subsequent processing by reinforcement learning methods.
- It was discovered that Bayesian belief networks can be combined with decision nodes and an incremental assessment algorithm to mimic human patterns of data reduction and knowledge representation.
- The human immunological system was identified as a possible model for a "bidirectional" distributed decision network.
- Initial work has identified a model-balancing technique, borrowed from linear system theory, that is a strong candidate for a pruning and model reduction method for large modular networks.

15. SUBJECT TERMS

Artificial Intelligence, Machine Learning, Distributed Systems, Robotics

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			John S. Bay
U	U	U	UU	8	19b. TELEPONE NUMBER *(Include area code)* (540) 231-5114

OFFICE OF NAVAL RESEARCH

END-OF-THE-YEAR REPORT
PUBLICATIONS/PATENTS/PRESENTATIONS/HONORS/STUDENT REPORT

For

GRANT: N00014-98-1-0779

PR Number 98PR06892-00

BEHAVIOR SELF-ORGANIZATION IN MULTI-AGENT LEARNING

John S. Bay
Hugh F. VanLandingham

Bradley Department of Electrical and Computer Engineering
Blacksburg, Virginia 24061-0111

July 30, 1999

Reproduction in whole, or in part, is permitted for any purpose of the United States Government

This document has been approved for public release and sale, its distribution is unlimited.

DTIC QUALITY INSPECTED 8

PART I. PUBLICATIONS/PATENTS/PRESENTATIONS/HONORS REPORT

PR Number:	98PR06892-00
Contract/Grant Number:	N00014-98-1-0779
Contract/Grant Title:	Behavior Self-Organization In Multi-Agent Learning
Principal Investigators:	John S. Bay
	Hugh F. VanLandingham
Mailing Address:	Bradley Department of Electrical and Computer Engineering
	Virginia Polytechnic Institute and State University
	Blacksburg, Virginia 24061-0111
Phone Number:	(540) 231-5114 (J. S. Bay)
Fax Number:	(540) 231-3362
E-mail Address:	bay@vt.edu, hughv@vt.edu
http address:	armyant.ee.vt.edu/mabl.html

a. Number of papers submitted to refereed journals, but not published: 0
b. Number of papers published in refereed journals (for each, provide a complete citation): 0
c. Number of books or chapters submitted, but not yet published: 0
d. Number of books or chapters published (for each, provide a complete citation): 0
e. Number of printed technical reports/non-refereed papers (for each, provide a complete citation): 0
f. Number of patents filed: 0
g. Number of patents granted (for each, provide a complete citation): 0
h. Number of invited presentations (for each, provide a complete citation): 0
i. Number of submitted presentations (for each, provide a complete citation): 0
j. Honors/Awards/Prizes for contract/grant employees (list attached): 1
(This might include Scientific Society Awards/Offices, Selection as Editors, Promotions, Faculty Awards/Offices, etc.)

John Bay was elected to the executive committee of the IEEE Virginia Mountain Section.

k. Total number of Full-time equivalent Graduate Students and Post-Doctoral associates supported during this period, under this PR number: 2
Graduate Students: 3
Post-Doctoral Associates: 0
including the number of,
Female Graduate Students: 1
Female Post-Doctoral Associates: 0
the number of
Minority* Graduate Students: 2 (one Turkish, one Egyptian)
Minority* Post-Doctoral Associates: 0
and, the number of

Asian Graduate Students: 1
Asian Post-Doctoral Associates: 0

1. Other funding (list agency, grant title, amount received this year, total amount, period of performance and a brief statement regarding the relationship of that research to your ONR grant)

"A Servo System Model and Adaptive Controller," proposal to Motion Control Systems, Inc., Radford, Virginia, $37,072, 8/17/98 – 8/16/99; PI: John Bay. No relationship to ONR grant.

"Technology Assessment for a Robotic Vacuum Cleaner," Servus Robots, LLC, of Richmond, Virginia, $8,333, 10/1/98 – 3/31/99; PIs: John Bay, C. Reinholtz, R. Sturges, and M. Deisenroth. No relationship to ONR grant.

"Technology Assessment for a Robotic Vacuum Cleaner," Virignia Center for Innovative Technology, $25,000, 10/1/98 – 3/31/99; PIs: John Bay, C. Reinholtz, R. Sturges, and M. Deisenroth. No relationship to ONR grant.

"Nonlinear Control of Dynamic Systems," Office of Naval Research (ONR) MURI, $7,250k, 9/96 to 8/01, PI: Ali Nayfeh, ONR point of contact: Kam Ng, (My support = 50% summer + 12-mo.GRA). No relationship to this ONR grant.

"Intelligent Control Systems Research," DuPont Chemical Co., $6,000, 6/1/1999 to 4/30/2000; PI: Hugh VanLandingham. No relation to ONR grant.

PART II. RESULTS AND PLANS

Principal Investigators:
Dr. John S. Bay (540) 231-5114
Dr. Hugh F. VanLandingham (540) 231-3297

Cognizant PNR Program Officer:
Dr. Teresa McMullen

Program Objective:

To develop methods for the design and control of cooperative multi-robotic systems by allowing independent intelligent modules to self-organize into collaborative structures.

RESULTS

There are four primary results of the first year of the project:

- It was discovered that clustering algorithms for pre-sorting high-dimensional datasets was not effective in improving subsequent processing by reinforcement learning methods. It had been hoped that pre-classification would better facilitate data processing in modular systems.
- It was discovered that Bayesian belief networks can be combined with decision nodes and an incremental assessment algorithm to mimic human patterns of data reduction and knowledge representation.
- The human immunological system was identified as a possible model for a distributed decision network. It was recently discovered that this system works "bidirectionally", that it, with model-based and data-driven characteristics, which we believe to be crucial to intelligent behavior.
- Initial work has identified a model-balancing technique, borrowed from linear system theory, that is a strong candidate for a pruning and model reduction method for large modular networks. This will allow us to avoid over- and under-fitting of observed data.

PLANS:

For the coming year our plans are to:

- Write a complete multi-robot exploration and learning program that will use on-line sensory data to evolve a cause/effect model of the robots' environment and each robot's functional relationship with the other robots. Each robot will generate an adaptive belief network that it will later use to guide its actions. A mobile robot will be prepared for use in year three as a physical testbed.
- Devise analytical methods for paring a large belief network by "balancing" the nodes so that each proposition can be compared as to its relative importance. Propositions that have little influence on the global problem will be pruned in order to condense experiential data into more general concepts.
- Further investigate the distributed mechanisms by which psychophysiological systems perform decision-making. We will attempt to find a mathematical or

algorithmic model for the adaptation that occurs due to immune system responses, and how these adaptations affect behavior.

GRADUATE STUDENTS:

Ferat Sahin, a Ph.D. student from Turkey.

Hossam Meshref, a Ph.D. student from Egypt.

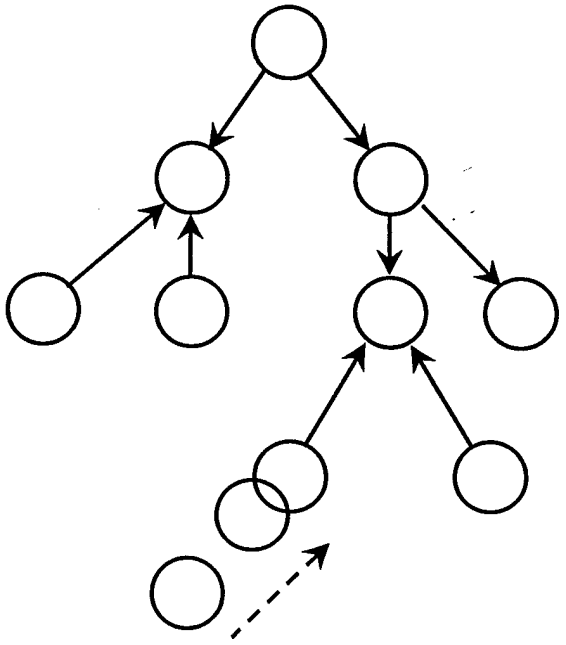
Samy El Shedied, a Ph.D. student from Egypt.

Yanhua Chen, an M.S. student from China (who has recently left the university to take industry employment).

BEHAVIOR SELF-ORGANIZATION IN MULTI-AGENT LEARNING SYSTEMS

J. S. Bay and H. F. VanLandingham
Virginia Tech

- Objective:
  - To use psycho-physiological knowledge models to inspire modular intelligent systems.
- Approach:
  - Allow independent modules to self-organize into adaptive structures that optimize global performance criteria.
- Accomplishments:
  - Identified modular learning methods amenable to analytic optimization techniques, testing performance relative to biological counterparts.
- Impact:
  - Potential controllers for mobile robots, distributed AI algorithms, multiple intelligent vehicles



Behavior modules self-organizing into cooperative units

Learning Bayesian Belief Networks

- Mimics human decision processes (in function, though not in structure)
- Supports model-based (deliberative) and data driven (reactive) decision-making
- Inherently adaptive to on-line evidence
- Potential applications in distributed decision-making and data-mining

Multi-Agent Immune System Model

- Agents in an artificial immune system (AIS) are a metaphor of the human immune system cells.
- Certain types of agent cooperation has been established by immunologists.
- A growing list of engineering applications are available in the literature.
- AIS provides excellent potential for adaptive behavior at the local level and useful behavior emerging at the global level.